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Embedded Human Computer Interaction

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Abstract

In this paper, human interaction with embedded or ubiquitous technology is considered. The techniques focus on the use of what might be termed "everyday" objects and actions as a means of controlling (or otherwise interacting with) technology. While this paper is not intended to be an exhaustive review, it does present a view of the immediate future of human–computer interaction (HCI) in which users move beyond the desktop to where interacting with technology becomes merged with other activity. At one level this places HCI in the context of other forms of personal and domestic technologies. At another level, this raises questions as to how people will interact with technologies of the future. Until now, HCI had often relied on people learning obscure command sets or learning to recognise words and objects on their computer screen. The most significant advance in HCI (the invention of the WIMP interface) is already some 40 years old. Thus, the future of HCI might be one in which people are encouraged (or at least allowed) to employ the skills that they have developed during their lives in order to interact with technology, rather than being forced to learn and perfect new skills. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

People interact with an enormous range of technology over and above the "personal computer" (PC) that sits on their desks at work and at home. Furthermore, many of the interactions with this gamut of non-PC technology can be more pleasurable, useful and important than the limited range of activities that PCs support; to be blunt, computers compute and, while they are good at doing all manner of tasks that involve data manipulation, there remain many things that they cannot do and that we probably would not expect them to do. Having said this, there is a growing interest in asking what would happen if non-PC technology was given (limited) computational capability.

The notion of a world of products that are able to communicate and interact independently of human intervention may well be the stuff of a frightening science fiction. An issue for ergonomists is not whether this vision represents a reality (there is sufficient evidence, for example, from the increasing level of computing in automobiles, that the concept is probable rather than merely possible), but rather how people will relate to such technology. Of specific concern, therefore, is how ought this future technology function, if it is to provide realistic, useful and beneficial support to the people who might use it?

Any paper that purports to present a vision of the future naturally suffers from lack of falsifiability (we will not know if the claims in this paper are correct until several years from now), and the dilemma of plausibility (in order to be acceptable, a design concept should sound plausible, but being plausible does not guarantee that the concept is of any use). Consequently, we consider proposals in terms of the following criteria:

(i) Will the proposed technology alter the manner in which people behave?
(ii) Will the changes in behaviour require people to learn new activities or modify existing activities?
(iii) Will the changes in behaviour be in support of the technology, e.g., to make it function appropriately, or in support of human activity, e.g., to improve some aspect of working or everyday life?

It is quite possible that the majority of the technologies considered in this paper will require people to significantly alter their behaviour in order to ensure that the technology functions—and the changes in behaviour

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will result in little or no benefit to the person using the technology. By way of illustration, a personal digital assistant (PDA) might require the user to learn a new way of writing (e.g., in order to form letters that the device is able to interpret), in order to enter information into an address book. Compare this with a paper address book, in which the user can write normally (so not need to adapt their behaviour for the device). Of course, one might defend the PDA in terms of its ability to interface directly and easily with a PC, or the range of additional functions it offers in comparison with the address book. Direct comparison between products always presents problems, as one is comparing "chalk and cheese". However, it remains a moot point as to what specific advantages one can offer in favour of a PDA over a paper address book. Having said this, there is surprisingly little published research into the ergonomics of everyday products, so it is not easy to determine how "new" technologies compare with alternative technologies to perform these activities.

2. Ubiquitous computing/ubiquitous technology

In a seminal paper, Weiser (1991) raised the notion of "ubiquitous computing" in which people and their worlds could be augmented with computational resources and capabilities. One can see this notion in the trend for people to carry their work, communications and entertainment equipment with them, e.g., the Walkman, the PDA, the Mobile Telephone. Each of these technologies provides access to some service or resource, e.g., music, appointments, contact details, or other people, and supports access from (more or less) any location. Thus, the technologies are ubiquitous in their geographical distribution (as anyone who has been annoyed by the tinny sounds of a Walkman or the overloud conversations of mobile telephone users of trains can testify). However, the concept of ubiquitous computing is much bigger than simply providing people with access to technology anywhere.

Abowd and Mynatt (2002) suggest that ubiquitous computing applications share three basic goals:

(i) *Natural interaction*: Everyday objects can serve as the "interfaces" to computing environments. While speech and pen-based computing have sought to provide natural interfaces to computers, there remain problems in their use and application (Noyes, 2001). An underlying assumption of ubiquitous computing is that the interaction between person and computer could be viewed as essentially a by-product of other activity.

(ii) *Smart technology*: Computing environments and the objects they contain can make decisions and perform actions based upon an awareness of "context". The technology will be able to interpret the activity of people, and use this interpretation to adapt its own behaviour.

(iii) *Communication*: The objects allow communication between devices, and between devices and people. At another level, the devices also allow people to share, capture and retrieve experiences. The "experiences" could be recorded simply as video and audio clips, but could also involve more sophisticated merging of data sources.

Ubiquitous computing has largely been the province of technology-led research and development. As with any attempt to "invent the future" there is a high level of scepticism as to whether people would want to use the technology or whether people would buy the technology. The broad aim in writing this paper is to introduce some of the concepts as technically feasible, i.e., working prototypes already exist, and then to explore the ergonomics implications of these "visions of the future".

2.1. Microprocessors and embedded systems

Of particular relevance to the development of ubiquitous computing is the "quiet revolution" of embedded systems, in which a collection of microprocessors can share information to manage more complex systems and operations. We call this a "quiet revolution" for the simple reason that the "intelligence" of domestic products has risen dramatically in a short period of time, with little or no acknowledgement from research communities (outside those who have been developing such products). Domestic products, automobiles and many other forms of technology have become imbued with increasing levels of intelligence. The primary source of this intelligence is the microprocessor that is used to control device operation. Thus, a typical microwave oven might contain a microprocessor to control the operation of the oven and to allow the user to enter different commands (from a limited set). Alternatively, a camera might contain microprocessors, e.g., the Canon EOS3 contains three microprocessors to control such functions as auto-focus (Anon, 1999).

There is little consideration of the microprocessor (and how people interact with the products it supports) in standard textbooks on human–computer interaction and even less in ergonomics textbooks. This reflects, in part, the relatively recent growth of the technology. At another (and we feel more important) level, this reflects the "invisible" nature of the technology (Norman, 1999). Researchers do not look too much at interacting with domestic products because such things are a "given". Thus, people are probably not aware that they are "programming a computer" when they wash their

clothes in their washing machine or cook a meal in their microwave. Having said this, there is a growing awareness of how people interact with non-computer technology, as evidenced by recent books examining the notion of "information appliance" and how people interact with intelligent products, e.g., Baumann and Thomas (2001); Bergman (2000); Gershenfield (1999).

What the microprocessor-based devices discussed above have in common is that they fall under the general heading of embedded systems. According to Wolf (2001) an embedded system can be defined as "…any device that includes a programmable computer but is not itself intended to be a general-purpose computer" (p. 2). Thus, a personal digital assistant (PDA) would count as an example of an embedded system, as would a mobile telephone or any number of domestic products that contain microprocessors. In this paper, we recognise a growing trend towards (embedded) computer systems that are distributed throughout the environment, and propose that this trend raises significant issues for ergonomics.

2.2. Inter-device communications

The BlueTooth standard governing inter-device communication could allow different devices to share information. An often-quoted example runs as follows: a user downloads a document from the computer in their office onto a handheld device, say a PDA, and goes to a colleague's office, perhaps in a different country. On arrival in the office, the user points the PDA at their colleague's printer and the document is printed. Recent work at Xerox (Lamming et al., 2000) proves the potential utility of the concept. While their work did not use BlueTooth, they show how access to documents at anytime and from anywhere can be a useful and popular application. Lamming et al. (2000) focussed on using the Nokia 9000 mobile telephone as a device to access remote electronic documents and to support transfer of these documents to printers and fax machines. The document is identified using its URL plus a signature for the document (this latter is incorporated for security), and this information is sent via infra-red to host receivers, e.g., on a printer. During initial trials, many users reported that they found the ability to access documents on their computer via the mobile handset to be very useful.

In order to determine whether such technology offers benefits over contemporary work practices, researchers often conduct trials with simple prototypes. For instance, Nilsson et al. (2000) describe a series of field-studies and participative design exercises related to the development of handheld mobile devices to support maintenance work in waste-water plants. The broad concept related to the instrumentation of people and places, through which data from sensors in the environment could be uploaded and inspected by pointing a handheld device at transmitter units. In this instance, pointing is a matter of directing a handheld device at objects in the environment.

2.3. Devices as tools

Baber (1997) suggests that one way to think of future interaction devices is as "tools", i.e., physical artifacts which can be manipulated and which can convey meaning in much the same way as handtools. He concludes that "…interaction devices can be developed as significant components of the computer systems, not only acting as transducers to convert user action to computer response, but communicating all manner of feedback to the user and supporting a greater variety of physical activity." (p. 276). The point of this statement is that one can develop means of interacting with computers that extend beyond the conventional keyboard/mouse concept and which incorporate everyday objects. The notion of ubiquitous computing and embedded systems raises the possibility that people can act on the world of computer objects in much the same way that they can act on the real world. This means that activity with everyday objects in the real world can lead to changes in the computer world. These examples promise new means of interacting with technology. One concern that we have is that, in the rush for technological development, people might merely function as the "hosts" for pervasive technology, carrying the technology between sites and supporting the interaction between devices but not actually interacting with the technology themselves. In other words, the "smart" technology would require "dumb" people to transport it. In this paper, we consider an alternative vision of ubiquitous computing. In particular, this paper focuses on the manner in which people will be able to interact with future technologies.

The "desktop metaphor" in human–computer interaction (HCI) sought to allow people to manipulate "files and folders" in much the same way that they would use the physical versions of such artefacts. It is obvious that the digital versions of files and folders allow few, if any, of the actions that people can perform on their real (physical) counterparts. However, there has been much interest in recent years as to the possibility of providing people with real files and folders that can, somehow, be used to interact with a computer.

2.4. What's wrong with WIMP/what's right with WIMP?

There is a general consensus in the ubiquitous computing community that the traditional WIMP (windows, icons, menus, pointing devices) interface of desktop PCs is inappropriate for future technologies. For example, Rhodes (1997) proposed that WIMP was

"harmful" for wearable and mobile systems for the following reasons:

(i) "The user has screen real-estate to burn": the argument is that WIMP, as a graphical user interface medium, requires significant graphics and screen space;

(ii) "The user has fine motor control": the argument is that WIMP, as a medium through which objects are selected using cursors, requires the user to be able to manipulate the cursor accurately;

(iii) "Digital information is the primary task": the argument is that WIMP assumes that the user is only attending to the display information on their computer screen.

While these arguments can each apply to the WIMP paradigm, we feel that there is some bias in this position, i.e., the WIMP paradigm has been portrayed in a negative light in order to damn it. However, recall some of the defining features of WIMP, e.g., putting "knowledge-in-the-world" rather than requiring "knowledge-in-the-head", by replacing commands with icons in order to reduce memory load, by having clear depiction of functions in order to allow users to guess which action to perform, and by having a clear mapping between user action and system function, or using multiple views of applications through the use of different windows. From these points, dispensing with the WIMP paradigm seems unduly wasteful of some useful design ideas. An alternative position is to determine how the defining features of WIMP can be applied to ubiquitous computing.

(i) Windows: Multiple views on different functions. The issue for ubiquitous computing becomes less of determining how to present many functions on a limited screen, and more of how one interleaves functions in the world with functions in the computer. In this respect, windows become both the user's view of the computer system and the medium through which they view the world. A significant issue, therefore, becomes how the computer and real worlds can be combined.

(ii) Icons: Physical embodiment of objects, commands and functions. Given that ubiquitous computing may have limitations on available display space, it is important to determine how one can represent information to the user. One option might be to use real folders (placed on a real desk) to "stand for" their digital counterpart. Another option might be to have objects in the world change their appearance with respect to status.

(iii) Menus: Presenting a limited set of options from which a person can select functions. Given that the notion of ubiquitous computing would link the computer and real worlds, it becomes important for the user to know what functions are available at any given place or time. Having some clear means of presenting to the user what s/he can do is clearly essential;

(iv) Pointing: selecting and manipulating objects. Rather than pointing merely being as the manipulation of cursors (which, while true of mice is not true of touchscreens), ubiquitous computing could have object selection as a physical interaction with real objects.

Each of these points is developed in the following sections. The central argument is that the WIMP paradigm can support future technology rather than act as a barrier to such developments.

3. Digital desks and table-top augmented reality

Some of the earliest work in support of the notion of ubiquitous computing was the Digital Desk project of Wellner (1993). In this work, a person could sit at a desk, with paper documents spread out in front of them and be able to mark, manipulate and read the documents as one normally does with paper. What makes the Digital Desk interesting is that a camera and projector system were mounted above the desk (see Fig. 1); thus the documents and the user's hands could be tracked to allow near-seamless integration of the world of real objects, i.e., paper documents, pens, etc., and the world of virtual objects, i.e., data and images stored on a computer. Imagine that you are reading a

Fig. 1. Basic concept of digital desk.

paper that shows a graph of performance changing over time, and you have conducted similar work—you want to compare the two graphs, so you call up the graph on your computer and have it overlaid on the graph in the paper.

It is interesting to compare Wellner's (1993) application of the Digital Desk concept with a much earlier proposal that shares some of these themes: in 1945, Vannevar Bush proposed the concept of a MEMEX which "…consists of a desk, [which] is primarily the piece of furniture at which he (*sic*) works. On the top are slanting translucent screens, on which material can be projected for convenient reading. There is a keyboard and sets of buttons and levers. Otherwise it looks like an ordinary desk." (Baecker and Buxton, 1990, p. 4). While Bush's (1945) account shares some features with the Digital Desk, i.e., a notion of projecting information, and the fact that it is a real-world object, i.e., a "…piece of furniture…", there are some fundamental differences: Bush (1945) saw the projection as occurring onto screens, whereas Wellner (1993) projects onto paper, and Bush (1945) saw interaction as arising through keyboards, buttons and levers, whereas Wellner (1993) uses hand movements and pen gestures. Thus, while one might marvel at Bush's (1945) foresight, it is more remarkable that Wellner (1993) is able to merge so well the worlds of digital information and everyday objects and activities.

Other forms of "table-top" augmented reality allow users to manipulate physical objects to control digital information. For example, Fitzmaurice et al. (1995) provide physical objects with "handles" that allow user to grasp, raise and move these objects in real space in order to effect change in virtual space. Ishii and Ullmer (1997) track user interaction with real objects (such as plastic models of buildings on a campus), and map these tracked data into a "tangible geospace", e.g., to alter the perspective of a projected map display. The BUILD-IT project of Fjeld et al. (1999) also utilises plastic models of objects as a means of interacting with an architectural design package (see Fig. 2).

The basic assumptions of the digital desk approach are to merge real-world objects with their digital counterparts. A variation of this idea is to produce virtual reality (VR) systems that allow the person to interact with a 3D space, e.g., using CAVEs. While VR lies outside the scope of this paper, CAVEs are an interesting development in that the person can be immersed in a virtual world without having to don head-mounted displays. A small version of a CAVE, the *Cubby* system, is shown in Fig. 3. In this environment, the user is able to select and manipulate virtual objects that appear to be floating in space.

In CAVEs, a computer-representation becomes part of the real world, e.g., the *cubby* system has a 3D projection of virtual objects that appear to hang in space. This echoes some of the central themes from augmented reality (AR), in which virtual objects become superimposed on the real world. This issue will be explored further later in the section on wearable computing. However, there have been some interesting developments in handheld systems that can be considered in this section. For example, Fitzmaurice (1993) demonstrated a device that uses a palm-held display to

Fig. 2. *Build-It* user interface (*source*: http://www.fjeld.ch/hci/photos/photo_01.htm)
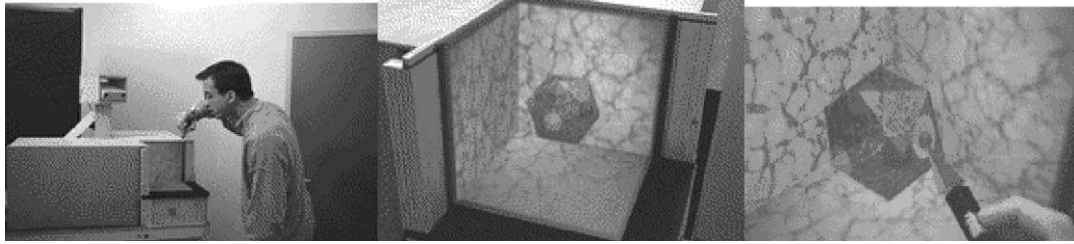
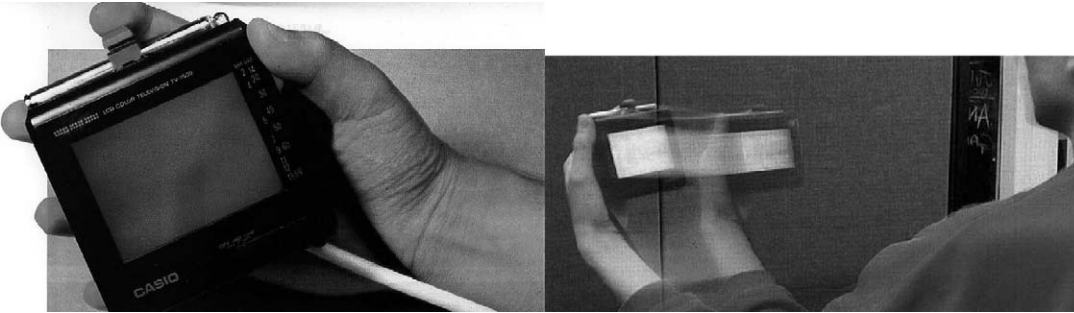Fig. 3. *Cubby* system (Djajadiningrat et al., 1997).

Fig. 4. *Chameleon* system. (Fitzmaurice, 1993).

overlay images onto the world (Fig. 4). As the user moves his/her hand, so the position of the device is tracked and the image modified. In this manner, the user "points" by moving the device and the display changes.

4. Tangible interfaces

In the applications of table-top augmented reality, user activity is primarily concerned with moving objects on a 2D surface. Consequently, this is similar to the notion of using two mice or pucks on a surface to interact with a computer. However, there are two reasons why tangible interfaces extend the dual-mouse paradigm:

(i) It is possible that the objects themselves can offer additional cues and feedback beyond the standard shapes of mice and pucks.
(ii) The objects can offer additional functionality to the user.

To consider the first proposal, i.e., that objects can offer additional cues, it would be beneficial to compare user performance with a mouse and with an object. Comparison of using a tangible interface with other forms of interaction is relatively scarce at present. In one study, Boud et al. (2000) demonstrate that the use of "real object", i.e., wooden blocks tracked using magnetic trackers, to move virtual objects, i.e., blocks on a Tower of Hanoi task, led to significant improvement in

performance in comparison with using a 3D mouse (see Fig. 5).

The study took place in a visually immersed environment, and it was suggested that the wooden blocks provided users with a range of haptic cues that facilitated their performance, e.g., participants using the wooden blocks could use the impact on block against pole to signal arrival at the destination. A further explanation for these differences in performance relates to the marked differences in strategies for object handling. For example, when using real objects participants would switch their visual attention to the end point of the move and not track the movement of the objects in space; whereas, in the 3D mouse conditions, participants' head movements followed the path of the virtual object. In other words, when using the 3D mouse the task was one of "dragging" an object between two points on the screen, whereas when using wooden blocks the task was one of moving a real object to its new location. What this study suggests is that using real objects leads to differences in performance that are not merely adaptations of human–computer interaction techniques, such as more efficient dragging, but show use of everyday actions in the computer-domain.

Recent developments on the theme of projected augmented reality systems seek to recognise objects in the world, through the use of labelled tiles that cause the computer to project specific images (Poupyrev et al., 2001). For example, a tile showing the symbol ß would be recognised by the vision system, and an image of a clock-face projected onto the tile. In a similar manner, Ullmer et al. (1998) concept of mediaBlocks uses small,

Fig. 5. Wooden blocks used in Tower of Hanoi (Boud et al., 2000).

tagged blocks that are linked to digital media. Placing the mediaBlocks in a rack calls the digital media to be "played" on a screen. The mediaBlocks are, consequently, more than merely "control" devices; they can capture or transfer or playback the digital media, acting as storage devices as well as editors. For example, a video clip could be played when one block is in position and a second block could be used to capture this clip, then a third block (perhaps containing video controls) could be used to edit the clip. In this way, physical objects become both the repositories, and means of controlling, digital information.

Developing this notion into educational technology, Wyeth and Wyeth (2001) report the use of "tangible blocks" for pre-school children. These blocks contain simple electronics to have sensor blocks respond to a stimulus, e.g., light, touch, sound, and output a value. Action blocks can produce an output, e.g., light, sound or vibration. Intervening logic blocks can then vary the responses made to sensors, e.g., a Light Sensor Block can be connected, via a Not Logic Block, to a Sound Action Block—in this configuration, when there is no light, a sound will be made. In their field trials, Wyeth and Wyeth (2001) found that the majority of the pre-school children who played with the blocks not only enjoyed the experience but also demonstrated an understanding of the logic involved.

4.1. Contactless data carriers

Contactless data carriers are used for automatic fare collection in public transport, for access control to hotel rooms or premises, or for electronic purse applications. Alternatively, bar code strips may be used to tag physical objects and link them to URLs, software documents, or software applications. As these data carriers may have the form of, or be built into, watch, or be stored into a purse or a pocket of the user, they lose the appearance of a tool and seamlessly become a part of the user's clothing. For example, Cooper et al. (1999) discuss the development of an electronic wallet. Interestingly, the study demonstrates that wallets are not merely used to carry financial items, such as money and credit cards, but also represent storage devices for the necessities of everyday life, e.g., season tickets, bus passes etc., as well as personal mementoes. This points to the proposal that, while contactless data carriers can function as devices to carry specific data, people might also look for these devices to carry other things (either because the carriers are designed to store a variety of data, or because the carriers are designed to function as aesthetically interesting and pleasing items).

A contactless data carrier can help make data transmission between devices more transparent and give these hidden operations again some link to real objects and the real world. Contactless memory sticks may be used to virtually move applications between computer systems—in reality these applications move via a network (see Fig. 6). Furthermore, it is likely that, in order to use the contactless data carriers effectively, people will need to learn to adapt their behaviour, e.g., by ensuring that the transmitter is not obscured or by placing the device near a receiver. This makes contactless technology similar to magic objects described in old fairy tales (Binsted, 2000), because they also required some background knowledge and
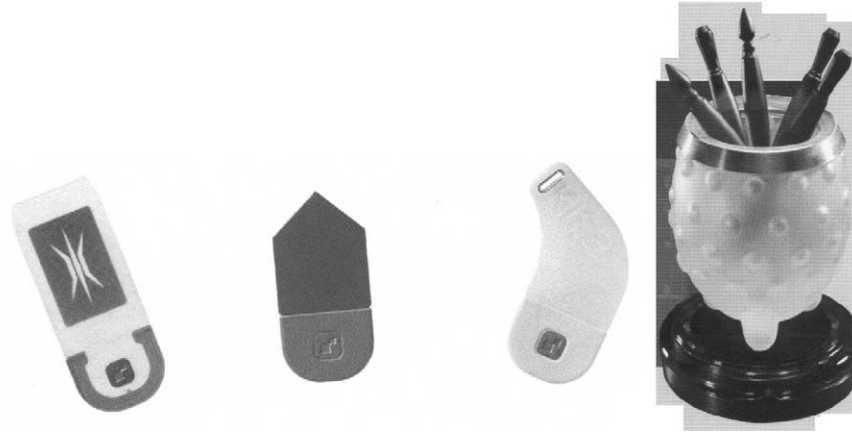
Fig. 6. Contactless data carriers in form of cards, phicons, and sticks for virtually moving software applications or data (Binsted, 2000).
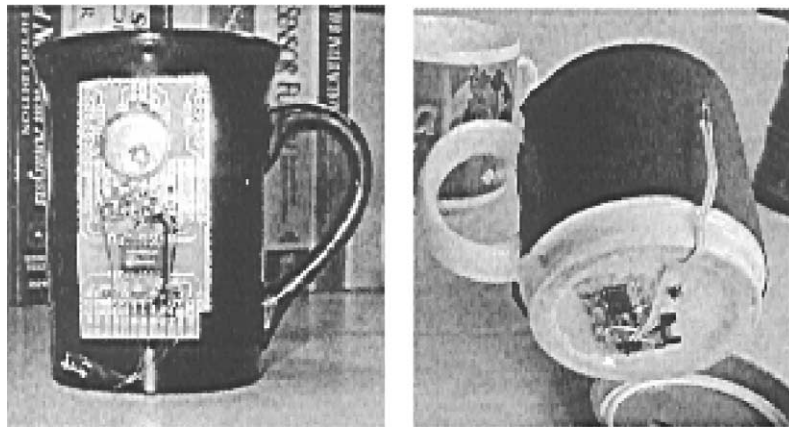

Fig. 7. The MediaCup (Gellerson et al., 1999).

dedicated movements or words used at the right time and place.

5. Interacting through real objects

The notion of interacting with real objects can also be extended to consider simple means of interacting *through* real objects. For instance, a project at Brunel University proposed that one could use a toaster to display weather forecasts, by using templates to cover the areas being toasted, e.g., a cloud to indicate the possibility of rain. In this example, technology could be networked to provide simple information displays to users. In a similar vein, the MediaCup project (Gellerson et al., 1999) allows a group of individuals to coordinate impromptu meetings on the basis of shared coffee breaks. The MediaCup (Fig. 7) uses a temperature sensor to detect whether the cup contains hot liquid, such as coffee, and a radio transmitter to inform other cups on the network that it is being used for

coffee. The other cups can indicate, e.g., via LEDs, to their users that someone is drinking coffee and that they could go and join them. The example is, of course, very simple but highlights several features of interest to this paper:

(i) The communication is incidental to the task at hand.
(ii) The communication is embedded in an everyday activity.
(iii) The technology is embedded in everyday objects.

Other possibilities to enhance everyday objects by technology have been explored during workshops at Helsinki University in Finland (Battarbee et al., 2000) and Interaction Design Institute Ivrea in Italy (Beardsley et al. 2001). The goal of these workshops was to find ways to enhance communities. Gaver and Pacenti (2001) developed and tested park benches that display information collected from the inhabitants of a suburb. Munro (2001) proposed a "community link" consisting
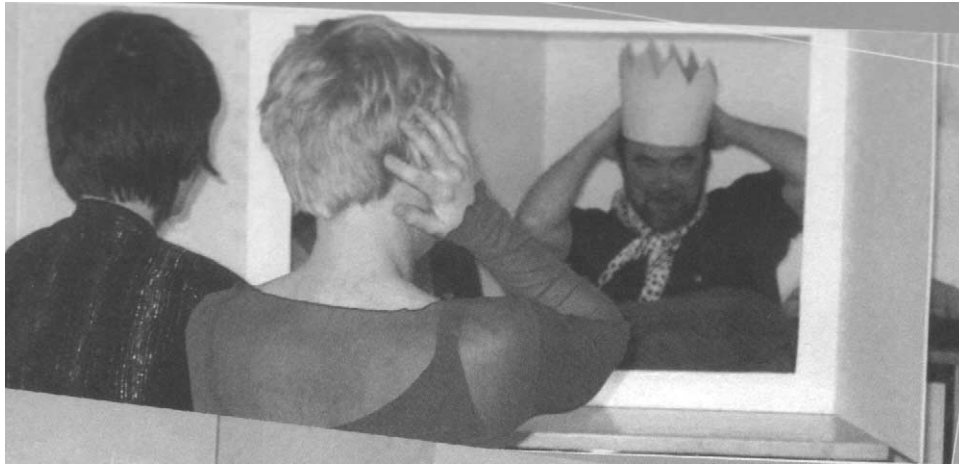
Fig. 8. Interacting through a "Magic Mirror".

of a camera balloon and a display balloon featuring a two-way audio link and a wireless data interface. The entity placed in public space can spark communication across sexes, social groups, and age groups. Binsted (2000) describes the idea of a mirror that can electronically transform the picture of the user that looks into the mirror into a fairy tale character has been created and tested with children and paper-mockups. Another use of the same technology has been created at the i3 Summer School in Ivrea (Beardsley et al., 2001) where the mirror transforms the age of the user, making young people look old and vice versa (a similar technology was on display at the Millennium Dome in London).

Fig. 8 shows a simple mock-up of the "magic mirror", in which participants relate to their "reflections" during the telling of a Fairy Tale. What is noteworthy here is that the participants could engage with their "reflections" not as real people but as themselves playing roles in the story being told. The emotional effect of such technology on the user is intended to facilitate the understanding between generations, create or improve empathy for elderly people and ultimately initiate a process of storytelling. The "magic mirror" can be implemented in form of a rectangular mirror hanging on a wall in a public building.

This section has reported a few of the many applications that are seeking to combine physical objects with virtual (computer) worlds. As the study of Boud et al. (2000) suggests, such combinations can significantly alter the manner in which people interact with objects on the computer. What is needed is further work into the combination of real and virtual objects, to study the ergonomics of such systems. A common failing in reports of "tangible interfaces" (and associated technologies) is the lack of appropriate ergonomics: there is little, if any study of user requirements, so one is not sure whether people would even want the technology; and there is little, if any, controlled user trial, so one is not sure whether the technology enhances user activity.

6. Wearing technology

If we consider wearable technology in general, i.e., any technology that a person can wear, then the most widespread item of technology in this context has become the mobile phone. We have seen the huge increase in mobile phones since the early 1990s (although the trend is starting to slow). Miniaturisation and long battery life made mobile phones an item which is "worn" by users during much of the daytime. One could assume that mobile phones will ultimately be worn by users for as many hours a day as glasses and wristwatches, creating a lifestyle which would not be possible any more without mobile phones.

Baber (2001) points out the people wear technology in order to provide access to information, to correct some problem or to augment the everyday world of the user. We have already discussed the role of the mobile telephone as a device for accessing information (either through calling other people or through calling services).

Alternatively, wearable computers could provide access to information relating to one's location, such as describing the building that you are facing (Feiner et al., 1997). A number of researchers in the realm of augmented reality have been considering the design of electronic tour-guides for museum visitors. These systems often rely on the visitor's wearing a transmitter, e.g., in the form of a badge, to signal their location. When the visitor's location has been determined, e.g., when the system identifies that the visitor is standing in front of a specific painting, then a commentary on that painting is provided—either through an auditory display (Not and Zancanero, 1998) or through overlaid

visual images (Baber et al., 2001). The notion of using a person's location to interact with a computer relates to the earlier work on Active Badges at Olivetti Research Lab or Xerox PARCTab. The user could wear a badge to indicate their identification (Want et al., 1992) so that they could, for instance, have telephone calls and emails sent to their current location in which workers in offices could be tracked in order to have messages, email, telephone calls sent to their current location. While such badges provide novel means of coordinating messaging, they also (obviously) introduce additional social concerns, e.g., if a badge "knows" a person's location, is it spying on them and can this information be used a management tool?

For the example of correcting problems: spectacles correct vision, hearing-aids correct hearing, pacemakers correct heart rhythm. Wearable computers could be seen as devices to correct some problem; in this case, the problem might be associated with cognition or with spatial awareness. Thus, Lamming and Flynn (1994) and Rhodes (1997) report devices that assist the wearer's by helping them to remember information, e.g., by displaying all documents that can be associated to a particular email or discussion. Other potential applications could include a face-recognition device that prompts the wearer the name of the person to whom they are speaking (Mann, 1997).

Wearable technology can augment the everyday world of the user. This is akin to the role of the Sony Walkman as a device to augment the everyday world with music. The wearable computer could, via a head-mounted display, provide circuit diagrams and instructions to maintenance engineers (Bass, 1996; Bass et al., 1995, 1997; Baber et al., 1998) or could provide treatment advice to paramedics (Baber et al., 1999a, b). In this application, the device acts as a repository for useful information. Fig. 9 shows a wearable computer (complete with eye-glass display) being used for simple maintenance work.

Wearable computers are also able to interact with wearers on a physiological level. Thus, one can produce devices that respond to the physiology of the wearer (Picard, 1997) or to the wearer's movement (Farringdon et al., 1999) or to changes in the environment (Schmidt et al., 1999). In the Lab of Tomorrow project, researchers are developing wearable technology that can record the movement of school children playing sports; the captured data (from accelerometers, pulse and temperature transducers) are sent via wireless link to a host PC in the classroom. The data will be used for teaching principles of energy conservation in physics.

A growing field of interest is the role of wearing technology for computer-supported cooperative work. In these applications, wearers can share information or images in order to work together on problems. To a certain extent, this can be seen as an extension of the use
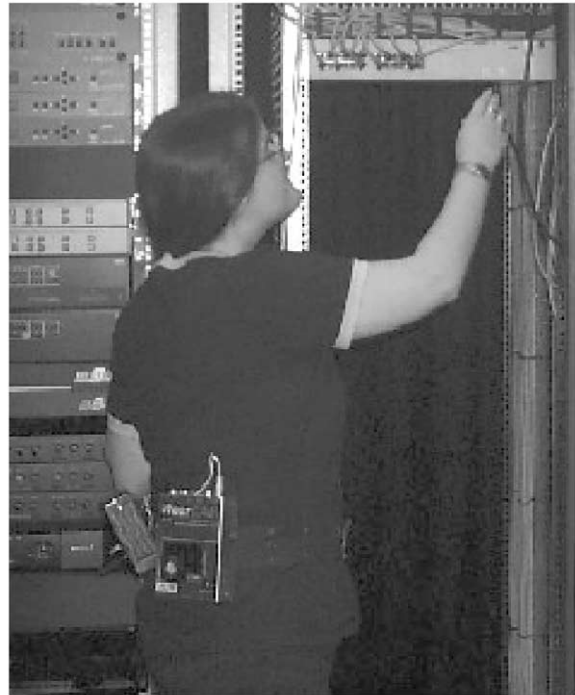

Fig. 9. Wearing a computer to support maintenance work (NB: head-mounted display fitted onto the spectacles).

of mobile telephones and computer conferencing facilities. However, there is an interesting field of application which has not been covered by wearable technology so far—the communication with people who surround the user.

Historic low-tech products that have this function are the so-called "sandwich board", a pair of information or advertisement panels attached to each other by two belts and worn by a person walking on the streets. An interactive version of this artifact is the "belly shop" where the panels feature drawers and shelves for merchandise. A modern version of this has been tested by one of the authors (KB) at HCII 2001 conference (see Fig. 10). Instead of merchandise, the front panel of the prototypes had two cardholders for own and others' business cards and one holder for fliers or paper abstracts.

The front and back panel surfaces were printed with the wearer's organisation's logo and an additional slogans, such as "HOME PAGE" or "TURN ROUND". During the test at HCII 2001 conference it became clear that the idea of wearing personal information can facilitate communication between the user (or wearer) and the other attendees. The flaw of the prototype was the lack of a cupholder!

Although being a low-tech device, it could be the starting point of a new category of appliances that enhance the work of salespersons, featuring a wearable computer with loudspeakers, displays for both the
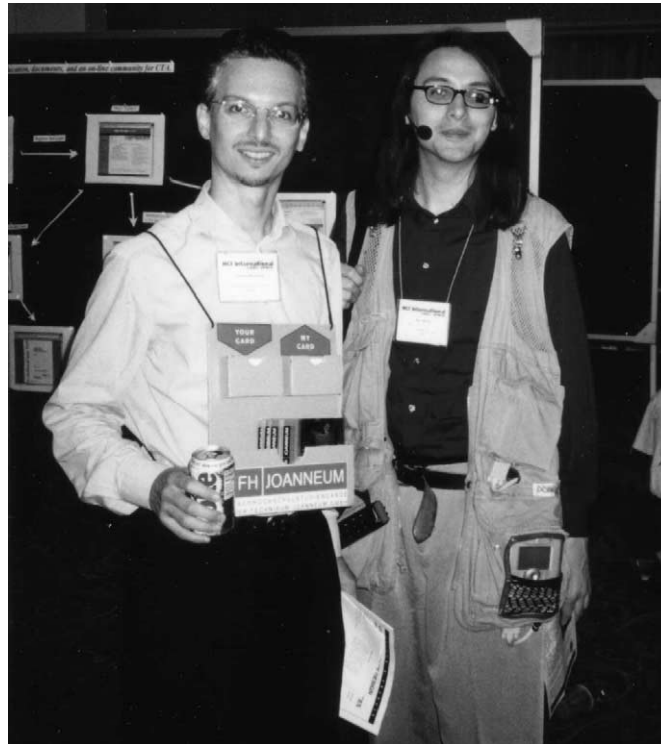
Fig. 10. Konrad Baumann wearing a physical homepage at HCII 2001 Conference, another participant wearing a computer built into his jacket, a chord keyboard and a headset.

Table 1
Features of context

Reference markers	Past	Current	Future
Event	Stored in diary	Incoming message	Reminder of meeting
Environment	Stored in maps	Location	Destination
Task	Previous actions	Current performance	To do list
Person	Stored photo/name	Physiological status	Medication reminder
Artifact	Virtual messages	Status display	Maintenance call

wearer and the people surrounding him/her, contactless data interfaces, etc. Basically the described appliance could have the full functionality of a personal or company website, making it a "wearable homepage". Indeed, several researchers have examined the potential role of "badges" for delegates to share information. A commercial version of this concept is the "lovegety"; an electronic badge that transmits simple data, e.g., gender, interests, type of relationship wanted, to other badge wearers (Iwatani, 1998). When two badges match on defined parameters, then they signal to their wearers that a local badge is responding (Its possible that one of the reasons why the product was not hugely successful was that boys and girls entered different "types of relationship" into their badges!) Similar projects have been reported for conference attendees relating to research topics of interest.

7. Context

As mentioned in the previous section, a significant aspect of embedded computing is the ability of the technology to respond to changes in context. Unfortunately, there remains a distinct lack of agreement as to what constitutes "context". Abowd and Mynatt (2002) suggest that one can think of context in terms of Who is using the system; What the system is being used for; Where the system is being used; When the system is being used and Why the system is being used. This provides an initial avenue into the problem of defining context. Baber et al. (1999a, b) suggested the following classification scheme:

Table 1 pairs reference markers, i.e., the element that is being defined, with simple demarcations of time. Thus, context could be defined in terms of a combina-

tion of reference markers that have different information relating to whether the information is stored or whether it is predicted, or whether it is being captured at the moment. Most of the examples are reasonably self-explanatory, although, the ⟨artifact⟩⟨past⟩ entry of "virtual messages" refers to the notion of leaving a message at a location that can only be picked up by someone with the appropriate technology, e.g., one could leave a text message on the card-swipe of a secure door and when the appropriate person enters, they could collect the message. One could further combine these examples into new products, e.g., combining ⟨event⟩⟨current⟩: incoming call; with ⟨task⟩⟨current⟩: sitting in a meeting and ⟨environment⟩⟨current⟩: in the manager's office, could lead to a device that recognises what is happening, does not seek to disturb you and routes the call to an answerphone.

8. Types of interaction

Fig. 11 defines three types of activity in which one might anticipate user's of ubiquitous computers will engage: using the interaction and display devices associated with the computer, and domain activity. The intersection of each pair of circles represents a specific form of dialogue. This assumes that "dialogue" involves at least two actions on the part of the user, i.e., some form of operation on a device, and some form of receipt of feedback from the device. The activities in the circles, if taken alone, do not necessarily constitute dialogue.

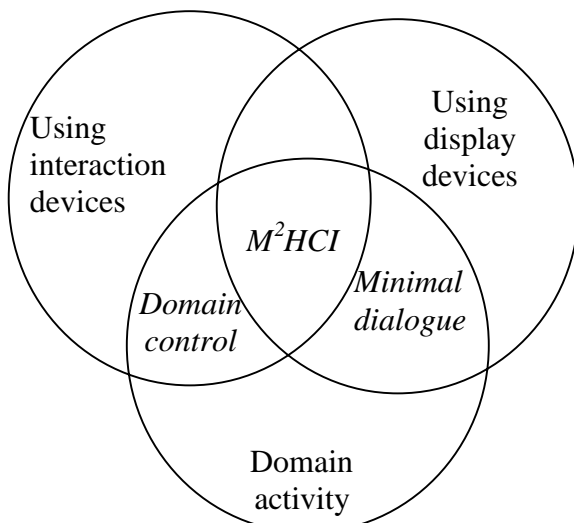Between using interaction devices and using display devices is the "conventional" view of dialogue, as presented in HCI. HCI dialogue involves a user employing a general purpose device, such as a mouse or keyboard, to act upon "virtual objects" on the computer display in order to modify the state of the computer. Typically, the computer has a large range of possible states, depending of the application software. In this view, a dialogue involves the user focusing full attention on the computer, and the computer responding to user input. In "desktop" applications, it makes sense to assume that the task of using the computer will be the user's focus of attention. However, for ubiquitous computers it is likely that the user will need to divide attention between using the computer and performing other activities in the world. Thus, the relationship between user and computer will change when the computer is worn and this will affect the type of dialogue required. This means that notions of HCI dialogue fail to cover the significant relationship between domain, computer and user.

The interaction between using interaction devices and domain activity could be taken to represent "everyday tasks". In this form of dialogue, the user will employ a special purpose device, e.g., a light switch, to act on physical objects in order to change the state of the object. Typically, the objects have a very limited set of states. The interaction device operates directly on the domain to exert some form of control (e.g., using a TV channel-changer). The user acts on real objects that exist outside of "computer space". In this instance, "dialogue" is now a different activity from that seen in HCI; indeed, readers might not like to think of turning a light on and off as a form of "dialogue" (although it is hoped that the previous discussion has indicated how it could be). If the user was to use physical objects to effect changes in a computer, then one would meet the notion of tangible user interfaces, e.g., one could move plastic models of buildings around the map of a university campus to modify graphical displays.

The intersection between using display devices and domain activity is dubbed minimal dialogue. Rather than users employing some form of interaction device, they will engage in everyday activity, such as walking around a museum. The people's movements will be sensed by devices in the environment, and the activation of sensors used to modify the state of the environment. This means that users do not need to engage in lengthy dialogue with the computer, nor that they need to switch their attention from the domain to a computer. For example, in some of our laboratories, lights are switched on when movement is detected, i.e., when you walk into the room, the lights come on. Linking the notion of movement sensing to a computer could lead to information displays that are a associated with specific locations, e.g., when a person walks up to a painting, their presence is detected, e.g., through infra-red sensors, and a description of the painting is presented to them.

Fig. 11. Types of dialogues (from Baber, 2001).

Finally, the intersection of all three circles is termed multimodal HCI (M²HCI). In this case, users will be conducting dialogue through several sensory modalities, with several objects, and with two domains (computer and world). In this instance, the user might be acting upon more than one object and using more than one sensory modality. An example might be making a telephone call on a mobile phone while driving a car. It is proposed that the issue of multimodal HCI will be central to the development of future computer systems, but is one that we currently have relatively limited understanding of the psychology of such activity.

Interacting with ubiquitous computers differs from conventional HCI, and these differences can be captured by three dialogue types: domain control, minimal dialogue, and M²HCI. These dialogue types allow designers to explore alternative forms of interacting with ubiquitous computers. For example, you may need to develop a product to allow someone to check email when they arrive in their office. A domain control dialogue has a switch on the wall that the user can press to listen to a read-out of all email; a minimal dialogue uses the same display but is activated when the user stands in one part of the office; M²HCI combines moving around the office with speech control to act on the email through the computer, HCI requires performing standard email access; These are not intended as credible designs, but show how the dialogue types can lead to different concepts.

9. Discussion

An "intelligent room" might have a collection of temperature sensors and a sensor to detect the number of people who have walked into the room. On the basis of the number of people in the room, the "intelligent room" might make some prediction as to what an optimal temperature might be and then seek to adjust the heating in the room to reach that optimal level, using its temperature sensors to assess the current levels. This example raises simple (but fundamental) issues for ergonomics relating to such technology: what if the people in the room begin to feel too warm? In other words, what opportunity will there be for the people in the "intelligent room" to interact with and exercise control over the environment? Further, how would the people in the room react to a system that knows that they are present, i.e., spying on them? Finally, what benefits will people get from the technology, and how will the technology influence their behaviour? These issues, and others raised in this paper, point to a significant role that ergonomics could play in the development of these technologies; the definition of novel means of evaluating and specifying the technology in terms of its influence of the people using it.

The significant challenges are less to do with technology than to do with how people will respond to embedded systems. At one level, this is simply another way of asking "what is the killer application"? However, this misses the point that "killer applications" are already on the market and in people's homes, in the form of the myriad embedded systems that we take for granted. At another, more significant, level the question should be how can technology enrich our everyday lives? As the pioneer of ubiquitous computing pointed out, "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." (Weiser, 1991, p. 933).

The challenges, therefore, that face ubiquitous computing are:

(i) How can technology be seamlessly embedded into everyday life?
(ii) How can "context" provide useful and appropriate ways of controlling such technology?
(iii) How can we know that the technology is actually any use to people?

Ergonomics can make significant contributions to each of these areas. For notions of "seamless embedding" of technology, ergonomics has always been concerned with appropriate task-fit. However, these new generations of technology need consideration of "fit" with activities that are less well defined than "tasks", and we need to hypothesise ways of describing "activity-fit". It is interesting to note how little we know about people actually using everyday technologies at the moment; Furthermore, it will be necessary to consider interaction with technology from a different perspective to the task-based approaches typically seen in ergonomics. The challenge is to describe "everyday activity" in a manner that can effectively capture the interwoven strands of context, goals, and emotions, and to use this description to provide a useful and appropriate basis for evaluating technology and proposing future designs.

As far as context is concerned, we need to be able to present holistic descriptions of human activity, and to show our understanding of such descriptions by providing "agents" with sufficient intelligence to provide useful support. In other words, we probably do not want future technology to behave like an annoying "back-seat driver" in our everyday life, but more like a useful ally. Furthermore, many of the examples (particularly those linked to badges and sensors) could easily be construed as "spies" that are covertly recording our behaviour and making decisions about us. An issue here is what authority should be given to these devices and what responsibility should we expect technology to take

for its action. Finally, we need to be able to develop new approaches to evaluation that can take concepts from task-based evaluation and extend these into investigating new forms of interaction with new forms of technology.

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